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Quantized Run Length Encoding QRLE -New Compression Method-: Application to ECG Transmission via IEEE802.11b WLAN Channel

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***Abstract*— A new method of signal compression, called Quantized Run Length Encoding QRLE, based upon the 'classical' run length method combined to discrete wavelet transform thresholding planned for a transmission via the WiFi IEEE 802.11b WLAN channel, simulated by Simulink/Matlab Integrated Development Environment IDE, is presented in this work. The key idea of our new method consists of quantifying each pair of zero followed by its corresponding run number, issued from the RLE, by one value consisting on the run number value plus an offset of predetermined integer value. In this work, the suitable offset was adjusted to 1024($\equiv 2^{10}$). This leads to quantizing the 'new' run number on 11 bits while the non null ECG thresholded ECG signal samples are quantized on 10 bits. The trivial advantage of this method is suppression, and consequently gaining, of all zeros. We have applied the proposed algorithm to extracted ECG signals, from the universal MIT-BIH arrhythmia data base. To evaluate the performance of the new QRLE compression method, we have simulated transmitting the compressed ECG signal via the Simulink/Maltab IEEE 802.11b WLAN noisy channel model. Besides the perceptible visual inspection, three criteria are used, in our evaluation phase, that are: compression ratio –CR-, the normalized root mean squared error (NRMSE), and the difference between the original and reconstructed versions of the ECG signal. The obtained results are around 10:1 in terms of CR, 0.07 in terms of NRMSE and a difference of about (10^{-4}) ± 0.02. Moreover, a comparative study with respect to selected ECG compression algorithms show the higher performance of the developed new technique called 'Quantized run length encoding QRLE'.**

Keywords—Compression, Run Length Encoding –RLE-, Quantization, Discrete Wavelet Transform Thresholding, ECG Signal, IEEE 802.11b Simulik/Matlab bloc

I. INTRODUCTION

Telemedicine is defined as the provision of health care and the sharing of medical knowledge remotely by means of telecommunication. Telemedicine is an essential component of the practice of distance medicine; it has become a very popular and important research issue in the field of biomedical technology [1-4]. Researchers began gradually when the telephone and fax machines, as well as other telecommunications, gained ground and unfolded roughly. It makes it possible to provide health services at a distance and in remote areas, the objective of which is to move to a good care of patients in a limited time [5]. For this, we use information and communication technologies. Telemedicine is therefore much developed in recent years, in parallel with the development of telecommunication technology, particularly the generalization of high-speed connections [6-8]. The telecardiology is a well-known branch of telemedicine that allows the remote detection of cardiovascular disease by means of telecommunication units. A classical chain of telemedicine is composed of several blocks: electrophysiological signal sampling, signal conditioning, electrophysiological signal pretreatment, signal conditioning, compression and storage, transmission channel is the last stage that makes a train between the emission and reception, signals and images are transmitted through transmission channels, whatever their nature and the last block is decompression and reception. Mobile telemedicine is new in the telemedicine sector [9]. It exploits developments in the mobile network for medical applications. In the hospital environment, WLAN networks are very convenient, regarded to wired local area network, for several reasons: installation flexibility, lower cost, and wider coverage. The Wireless Local Area Network (WLAN) appeared to cover a broadband radio of several rates. By connecting multiple nodes and equipments in cities that encompass places and require remote information transmission to the general public and connect to a core network such as the Ethernet network that also exists in public places, airports. There are several WLAN standards whose first wireless LANs were introduced to replace wired networks. There are three categories of wireless networks: The wireless personal network (also called individual wireless network or home wireless network and noted WPAN for Wireless Personal Area Network) concerns wireless networks with a short range: of the order of a few tens of meters; there is mainly Bluetooth. There are different types of wireless local area networks WLAN: WIFI, HYPERLAN and Home RF, which correspond to a high bandwidth network and cover a relatively small geographical area installed in public places, the different wireless network technologies can emit up to 100 meters. The Wireless Metropolitan Area Network (WMAN) has access to broadband fixed-band radio and rectified in IEEE 802.16 framework; there are several categories: GSM, GPRS and UMTS ... Two WLAN standards are defined which are IEEE802.11 and hyper LAN. The IEEE 802.11 is a standard for the 2.4GHz and 5.4 GHz bands, the IEEE 802.11 standard called "Wireless Ethernet". It can use three different types of physical media: frequency hopping spread spectrum –FHSS-, direct sequence spread spectrum –DSSS-, and infrared –IR-[10]. To ensure reconstruction fidelity, a primordial condition in biomedicine, a higher digitalization resolution is required in processing electrophysiological signals (ECG, EEG, EMG...).This demands a huge

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transmission bandwidth that is unavailable, in most of cases. As a classical solution to this situation is data (or signal) compression process [11]. Typical automated signal processing medical systems acquire a large amount of data that is difficult to store and transmit. Compression involves reducing the amount of data needed to describe the information. It is the technique of manipulating a set of initial data by a given coding to gain some storage space. Note that compression has two main axes: lossy compression and lossless compression. In order to achieve these effects, it is desirable to find a method to reduce the amount of data without loss of important information. In the case of a lossless compression, the information (signal, sound, image ...) reconstructed after decompression is identical to the original data. No disturbance is introduced on the bits of the information. Thus, any treatment performed will provide the same results whether the information is compressed or not. On the other hand, lossy compression consists in introducing an irreversible disturbance but which allows a much greater compression than that obtained by lossless methods. There is a wide variety of information compression techniques. In order to compare these methods, different criteria are needed. Four global criteria make it possible to evaluate the performance of a compression system [11]:

• The compression ratio measures the reduction of the data volume relative to the size of the initial file.

• Distortion, as part of a lossy compression method, measures the quality of information retrieved from original information.

• The complexity of the algorithm and its ease of implementation.

• Robustness of the code due to transmission errors introduced by the transmission channel.

Most compression methods aim at removing the redundancy present in the signal so as to reduce the number of bits necessary for its representation.

There are two main families of compression techniques:

• lossless compression (conservative): It is carried out for the reconstruction of exact data without loss of information, one speaks about reversible algorithm. The compacted representation of the information makes it possible to reconstruct the entirety of the original representation, by applying the inverse algorithm.

• Lossy compression (with distortions): It is performed with a controlled loss of information and is referred to as an irreversible algorithm. Indeed, the original representation. It is thus necessary, at the time of the diffusion of the information, to extrapolate to restore information as close as possible to the original information.

This first compression family is the largest and most common. The vast majority of algorithms developed are conservative algorithms. As its name implies, this implies that a compressed file then uncompressed will be exactly the same as the original: no data will be altered. Obviously, this is essential for all that concerns the compression of text files or executables. The best known methods are: entropic coding [12], Run-Length Encoding –RLE-, Huffman [13], arithmetic coding [14], Delta coding [15].

Non-conservative (lossy) compression consists of analyzing the content of an information, treating redundancy, and also removing elements whose presence is not considered necessary according to certain physiological criteria. Non-conservative data compression allows some loss of accuracy in exchange for significantly increased compression. It shows its effectiveness when applied to scanned images and sounds.

For cardiac signals, the application of compression algorithms with loss of ECG signal has been the subject of a great many researches. A wide variety of techniques for ECG signal compression have been proposed over the last forty years. These techniques are useful in a wide variety of applications (diagnosis through monitoring, patient monitoring, etc. ...).

The classification of compression methods is not precise and some compression algorithms can be classified into two or more categories. For direct methods, the signal samples are directly manipulated to provide compression; we quote mainly: Amplitude Zone Time Epoch Coding (AZTEC) method [16], SAPA (Scan Along Polygonal Approximation) [17], and KLT (Karhunen- Leove transform) [18]. For transformation methods, the original samples are subjected to a (linear) transformation and compression is performed in the new domain; we quote mainly: quasi-spectral transformations (Walsh and Haar) [19], the discrete cosine transform (DCT), wavelet representations [20-23] (wavelet packets [24-25], non-orthogonal wavelet transforms [26], EZW: Embedded Zero tree of Wavelet coefficients and SPIHT: Set Partitioning In Hierarchical Trees [27-28]), algorithm LZW (Lempel-Ziv-Welsh). More recently, advanced research has been done on the conversion of wavelets including the hybrid wavelet transforms [29] and adaptive thresholding [30]. For parametric methods, a preprocessor is used to extract some signal characteristics that will be used during the reconstruction. Most of the existing techniques for ECG signal compression fall into two of three categories: direct methods and transformation methods. Direct techniques of data compression have shown a more efficient performance than transformation techniques especially with regard to processing speed and generally to compression ratio. Although parametric methods usually have greater computational complexity, the algorithms that have recently joined this group, and are based on a beat codebook, appear to have the best compression performances.

II. BACKGROUND THEORY

The paper is aimed to present, discuss and evaluate our new compression method based on a combination of the well known RLE (Run Length encoding) compression method and an efficient quantization technique. The proposed quantization technique has double tasks: first, replaces a couple (zero and its run number in the classical RLE) by just one value, and second, it differentiates between null and non-null samples by an offset. These double tasks have, respectively, both benefits that are: improving compression ratio and reducing reconstruction error.

To evaluate the performance of our new proposed compression method called 'Quantized Run Length Encoding QRLE', we make an analysis of a complete chain of transmission/reception of compressed ECG signal via the Simulink/Matlab simulated WLAN IEEE802.11b channel. We mention that thresholding process, in our work, is based on wavelet transform denoising.

A. Wavelet Analysis

The wavelets come from what is called the mother wave. It is a representation of a signal L^2, by a base of wavelets which are only dilated and translated versions of the mother wave. The representation of a continuous signal x (t) by a wavelet basis is given by [31-34]:

$$x(t) = \sum W(a,b).\psi_{a,b}(t) \quad (1)$$

where W (a, b) is the weighting of the contribution of the wavelet $\psi_{a,b}$ related to the mother wave.
The analyzing functions are defined by [35-37]:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi(\frac{t-b}{a}) \quad (2)$$

where 'a' is the scale and 'b' is the translation in time.

B. Wavelet Denoising and Acronyms

The wavelet function provides a simple method to extract the white noise, this noise existed in all the frequencies, the difficulty of the noise reduction in the capacity of this noise is to transform the signal in wavelets and one eliminates with all the resolutions for the coefficients that are greater than a certain threshold and then reconstruct the signal with the remaining coefficients, but for a good success of the operation of noise cancellation orthogonal wavelets are used, the small coefficients are eliminated [38-39].

The model considered for denoising is conventional - the measured signal x is a sum of an informative signal s and a measurement noise r:

$$x(t) = s(t) + r(t) \quad (3)$$

where the noise r is modeled as Gaussian zero mean white noise with a variance of σ^2.

Thresholding is an operation allowing, among other things, the denoising of the signal; the coefficients of the details are generally thresholded. There are two types of hard and soft thresholding, hence the expressions given by (D. Donoho 1992):

$$\begin{cases} T_{soft} = \text{sign}(x).(|x| - Thr) \\ T_{hard} = x.1(|x| > Thr) \end{cases} \quad (4)$$

where the threshold value is given by [40-41]:

$$Thr = \sigma\sqrt{2\log(N)} \quad (5)$$

In the case of the noise given in equation (2), its variance can be estimated from the median absolute deviation of its detail coefficients (d_j), with j=1.L, and is computed as follows:

$$\sigma = \frac{MAD(|dj|)}{0.6745} \quad (6)$$

C. Run-Length Coding

This is one of the simplest modes of compression: any sequence of identical bits or characters is replaced by a pair (number of occurrences, bit or repeated character).

It is simply a question of replacing successive identical signifying elements by only one of them, followed by the number of repetitions. This process may seem simple and inefficient if we try to apply it, for example, to a text, the many repetitions of letters would only bring a derisory cuts. On the other hand, if it is applied on a database with considerable redundancies, for example the colors of the pixels adjacent to an image or the ECG signal by exploiting its characteristics, as in the isoelectric ECG signal segments, the method can be very effective.

Figure 1 illustrates an example of a particular run length encoding that processes only the zeros of a dataset containing a zero run. Each time the encoder encounters a zero in its data entry, two values are written to its output data. The first of these values is a zero, the second value is the number of zeros in the sequence.

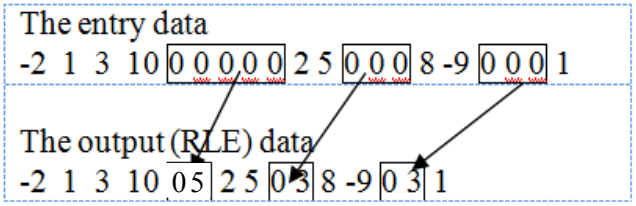

Fig. 1. Run-length RLE coding example.

D. Quantized Run-Length Encoding QRLE

Our key idea of the 'new' Quantized Run-Length Encoding QRLE is resumed as follows:

1. First of all, assume that the required quantization resolution, for the QRLE, is **(L+1)** bits
2. The value 'L' is determined as follows:
   $\{L = ceil(M) \mid M = log_2[MAX(signal\ samples)]\}$
   where ***ceil*** is the ceiling function and ***MAX*** is the maximum value.
   In other words, L is the smallest integer that is greater than or equal to base 2 logarithm of the maximum value of the unipolar signal samples.
   By taking the reference value for the digitization process as MAX(signal samples), it is guaranteed that binary representation of signal samples occupies at most L bits. Recalling the required quantization resolution is (L+1), the MSB (Most Significant Bit) is necessarily '0' as all the signal samples values are strictly less than 2^L.
3. After executing the run-length encoding, each pair of zero value followed by its run value is replaced by 'one' value given by the run value plus an offset value that equals 2^L. This procedure leads to that the MSB (Most Significant Bit), of the QRLE binary word (L+1) bits, is necessarily '1' as all the 'new' run values are strictly greater than 2^L.

Based on the previous example (Figure 1), the result of applying the QRLE technique is exhibited on the following figure 2.

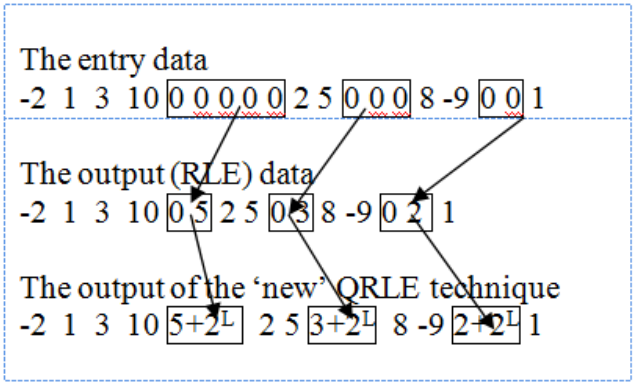
The entry data
-2 1 3 10 0 0 0 0 0 2 5 0 0 0 8 -9 0 0 1
The output (RLE) data
-2 1 3 10 0 5 2 5 0 3 8 -9 0 2 1
The output of the 'new' QRLE technique
-2 1 3 10 5+2^L 2 5 3+2^L 8 -9 2+2^L 1

Fig. 2. 'New' Quantized Run-length RLE encoding example.

Besides this considerable gain in compression ratio, a so remarkable benefit of this technique is resulted. The run length decoding (at the receiver end point of a telecommunication system) depends, in essence, on recovering the zero values. However, in practice, under , unavoidable, noisy channel circumstances, completely 'accurate' recovering of these zero values is not guaranteed. On the other hand, combining the zero value and its corresponding run number in one value added to an offset makes the detection more robust as the distance between non null samples and null ones is significant.

E. WLAN IEEE802.11b

IEEE 802.11b is the evolution of the 802.11 standard for the 2.4 GHz band, with a theoretical range of about 100 m, we can simultaneously use 3 bands 22 MHz channels with theoretical bit rate of 11 M b/ s so without any interference with each a bit rate of 11 Mb / s. We are interested in the wireless local area network standard IEEE.802.11b (WIFI), because it is widely used in the world among these benefits: Mobility where users are satisfied with freedom in the wireless network, ease and flexibility are easy to manage and are used in temporal locations and the cost of installation is more expensive, but the maintenance cost is lower than installation that is scalable.

The WLAN model IEEE802.11b under Simulink / Matlab is characterized by sub-blocks:

- Initiation of parameters;
- Digital modulation and demodulation;
- Spreading and spreading by BARKER sequence;
-Both sampling operations: oversampling and downsampling;
- BER (Bit Error Rate) calculation.

The implementation of the IEEE802.11b WLAN communication under Simulink / Matlab consists of three main phases [42-45]: the first phase is the initialization of the parameters (the Barker sequence, the one-bit delay, the delay of an addition of a chip, the ratio Es / No {Es is the energy of a bit and No is the spectral density of the power} and the construction of data to be transmitted (operation of the quantization of data).

The second phase is the transmission which gathers DBPSK modulation, Barker sequence spreading and the operation of the oversampling. The last phase is reception which groups the operation of downsampling, dispreading, DBPSK demodulation.

III. ALGORITHM DESCRIPTION

The compression algorithm consists of three phases: ECG pre-procession, QRLE compression and 16 bits packtization.

A. ECG pre-procession

First, in the pre-processing phase, the ECG signal is retrieved from the universal MIT-BIH Arrhythmia Database [46] and, next, the ECG records are portioned into segments of 8192 samples ($\equiv 2^{13}$).

B. QRLE compression

The compression phase consists on, firstly, applying the discrete wavelet transform to the ECG signal samples and, next, thresholding the wavelet coefficients of the signal. Secondly, the Quantized Run-Length Coding (QRLE) is applied to the generated thresholded detail coefficients of the ECG signal.

It is worthy to note that we perform the binary conversion of each compressed wavelet detail sequence apart.

The digitization of samples is performed as follows:

for i=1:N % N is the level of DWT decomposition
Compute the minimum of detail(i) : min_D(i);
Elevate the detail(i) by min_D(i) to suppress the negative part: Elev_Dt(i);
Compute the new maximum value of the elevated detail(i): max_Pos_Det(i) ;
Quantize samples as: $q(\mathrm{i}) = \frac{\mathrm{Elev\_Dt(i)} * (2^{10}-1)}{\mathrm{max\_Pos\_Det(i)}}$;
end

The two first instructions transform a bipolar signal to unipolar one. This procedure overcomes the drawback of positive and negative ranges inequality. Taking into account the disparity of the DWT resolution level peak to peak values, using a digitization uniform reference value leads to enormous quantization error value for the DWT detail levels with lower peak to peak values. The two last instructions update the digitization reference value for each DWT resolution level. This procedure ensures optimal recovering of the DWT detail sequences at the reception endpoint.

By this mechanism, after applying the QRLE approach, the 'new' zero run length values occupy, necessarily, more than 10 bits however the rest of non null values occupy, at most, 10 bits. This makes easier recovering the thresholded ECG signal at receiving phase by distinguishing between the non null samples and thresholded ones (the zero values).

C. 16 bits packtization

This procedure adapts the ECG compressed signal to the WLAN IEEE802.11b channel.

In sum, transmission phase consists of conveying the QRLE ECG signal coefficients via an AWGN IEEE802.11b channel with different SNRs.

The decompression phase consists of QRLE decoding and inverse DWT reconstruction.

The follwing figure 3 illustrates the flowchart of the developed algorithm based on the new QRLE compression method.

IV. Results and Discussion

To evaluate the performance of the ECG compression algorithm based QRLE method, we have applied it a simulated WLAN IEEE802.11b channel.

A. Learning Phase

The learning phase is a rudimentary operation aimed to choose the 'mother' wavelet function (Haar, DB4, DB10, SYM8, COIF2 and BIOR 3.1) and thresholding values the most suitable for the compression purpose. The assessment is fulfilled on the basis of the following measures: compression ratio –CR-, the normalized root mean squared error (NRMSE), and the difference between the original and reconstructed versions of the ECG signal. Table I lists the ECG compression results for the various wavelet functions listed above. Therefore, based on the compression ratio criteria, we opt, for the purposes of this work, for the Symlet wavelet of the 4th order hard thresholding with a value of three times the universal threshold value 'VisuShrink .

B. Improved vs. Classical RLE Methods

*W*e present, in this section, the 'added value' of our 'improved' approach –QRLE- with respect to the classical RLE method. A comparative study carried out using both methods is achieved. It is worthy to note that the obtained resulted, concerning the classical RLE method, are acquired from a previous work entitled "Run length encoding and wavelet transform based ECG compression algorithm for transmission via IEEE802.11b WLAN channel" [47].

We mention that we limit the DWT decomposition level to 5 in order to get a perfectly reconstructed ECG waves providing a compression ratio of about 11:1.

The following table II lists the obtained evaluation criteria results when applying both methods to a set of segments of ECG records data exhibiting each a specific characteristic.

TABLE I. Comparative Study Utilizing Different Wavelet Functions

Wavelet name	***CR***	***NRMSE (%)***	**Difference: *Mean ± standard deviation***
'Sym 4'	10.5431:1	0.1447	$(3.2714 \times 10^{-4}) \pm 0.0398$
'coif 2'	10.3959:1	0.7156	$(3.8995 \times 10^{-4}) \pm 0.1970$
'Sym 8'	10.0024:1	1.0294	$(3.6532 \times 10^{-4}) \pm 0.2832$
'db 4'	9.9177:1	0.1407	$(4.2650 \times 10^{-4}) \pm 0.0387$
'db 10'	8.9335:1	0.1434	$(4.3163 \times 10^{-4}) \pm 0.0395$
'Haar'	8.7335:1	0.9120	$(3.2316 \times 10^{-4}) \pm 0.2511$
'bior 3.1'	8.6964:1	0.7118	$(6.5777 \times 10^{-4}) \pm 0.1961$

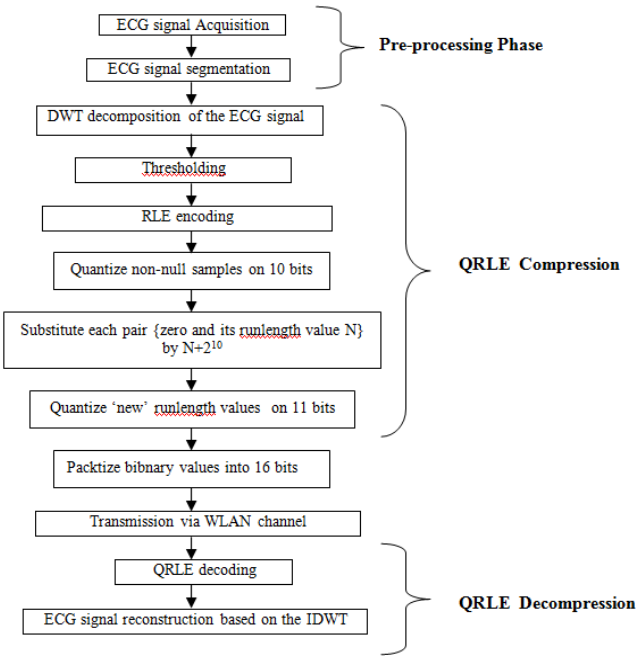
ECG signal Acquisition
ECG signal segmentation
Pre-processing Phase
DWT decomposition of the ECG signal
Thresholding
RLE encoding
Quantize non-null samples on 10 bits
Substitute each pair {zero and its runlength value N} by N+2^10
Quantize 'new' runlength values on 11 bits
QRLE Compression
Packtize bibnary values into 16 bits
Transmission via WLAN channel
QRLE decoding
ECG signal reconstruction based on the IDWT
QRLE Decompression

Fig. 3. The ECG based QRLE compression flowchart.

The used assessment metrics are:

$$CR = \frac{numbre\ of\ samples\ of\ the\ original\ signal}{number\ of\ samples\ of\ the\ compressed\ signal}$$

$$NRMSE = \sqrt{\frac{\sum_{i=1}^{N}\left[X_{org}(i) - X_{rec}(i)\right]^2}{\sum_{i=1}^{N} X_{org}(i)^2}} \times 100$$

As expected, the compression ratio is increased, using our improved RLE method –QRLE-, related to the classical RLE method. Moreover, a considerable gain of ECG signal reconstruction quality, assessed by NRMSE and the difference quantification as illustrated by table I, is obviously confirmed.

The following figure depicts, in the same order as in table I, the visual perception of applying both techniques for ECG signal compression.

The obtained numerical evaluation parameters as well as the visual inspection (illustrated by the figure below) demonstrate the great performance of our 'Improved' RLE method applied to ECG signal compression with a higher compression ratio and a very satisfactory reconstruction ECG signal quality.

C. Comparative Synthesis

To assess, more intensely, the performance of the proposed compression algorithm, which we called QRLE technique, we have performed a comparative study with a set of selected works as illustrated by table III.

Again, it is shown, obviously, the higher performance of the proposed method, called Quantized Run Length Encoding QRLE, acting as platform for ECG compression algorithm, in preserving high quality of the reconstructed ECG signal.

TABLE II. STATISTICAL ASSESSMENT PARAMETERS RELATED TO DIFFERENT HEART FEATURES USING IMPROVED AND CLASSIC RLE METHODS (QRLE VS. CLASSICAL RLE).

Cardiac characteristic	***ECG record (# of the segment)***	***QRLE vs. classical RLE***	***CR***	***NRMSE (%)***	***Difference: Mean ± standard deviation***
Normal ECG	100 (1)	Improved	11.3463:1	0.0690	$(1.2117 \times 10^{-4}) \pm 0.0190$
		Classical	9.5813:1	8.9491	0.0025± 0.0322
Abrupt transient	101 (8)	Improved	11.2527:1	0.0704	$(12 \times 10^{-4}) \pm 0.0192$
		Classical	9.5701:1	5.5449	0.0100± 0.0372
Baseline wandering	101 (7)	Improved	10.5431:1	0.1447	$(3.2714 \times 10^{-4}) \pm 0.0398$
		Classical	8.6050	29.9834	0.0045± 0.1331
APCs and PVCs;	233(1)	Improved	8.2831:1	0.1352	$(6.5881 \times 10^{-4}) \pm 0.0225$
		Classical	7.0865:1	13.7336	0.0089± 0.0818

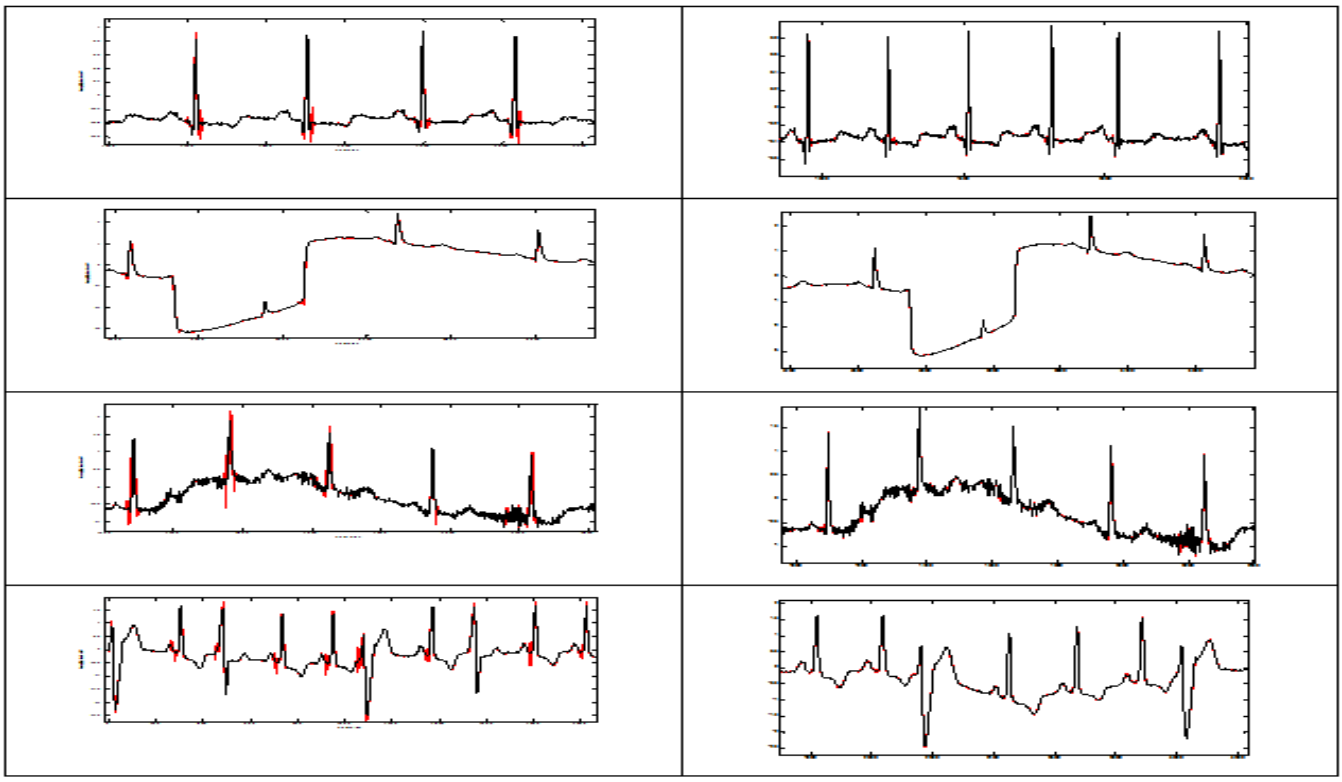

Fig. 4. The application of two compression algorithms ('QRLE' on the right side while the 'RLE' on the left side) to the ECG signal: the original ECG signal (in black color) and the reconstructed ECG signal (in red color); from top to bottom: Normal ECG; Abrupt transient; Huge baseline wandering; APCs and PVCs.

TABLE III. A COMPARAISON SYNTHESIS OF A SET OF WAVELET BASED ECG COMPRESSION ALGORITHMS.

ECG record	***Algorithm***	***Reference***	***CR***	***NRMSE %***
100 (12)	OZWC	Istepanian R et al 2000) [28]	8.16 :1	1.74
100(12)	WHOSC	Istepanian R et al 2001 [48]	15.8:1	1.74
117	Wavelet packets	HILTON 1997 [25]	8 :1	3.9
100	EZW	Xiaohua Zhou 2004 [49]	26.5 :1	35.3
117	SPHIT	Zhito Lu et al 2000 [27]	8 :1	1.18
101 (1)	Our algorithm		11.34:1	0.0690

V. CONCLUSION

A new proposed compression method which we have called 'Quantized run length encoding QRLE' has been presented in this paper. The finality of this work was to assess the performance of transmission the compressed ECG based QRLE method via the IEEE 802.11b WLAN noisy channel. The aim behind this improvement of the 'classical' RLE method has been to overcome limitations that were already raised in our previous work entitled "Run length encoding and wavelet transform based ECG compression algorithm for transmission via IEEE802.11b WLAN channel" [47].

In sum, the new QRLE method is based on the idea of substituting each pair of zero value and its corresponding run value by one value represented by the run value added to a predetermined offset. Furthermore,, this new technique overcomes the limitations due to dependence on the zero value detection at the receiver endpoint which is usually not easy task due to the unavoidable noise of the communication channel. This has been confirmed by the highly satisfactory quality of the reconstructed ECG signal.

To assess the performance of the QRLE based ECG compression algorithm; we have simulated the signal transmission via the IEEE 802.11b WLAN channel and performing measurements based on compression ratio value and reconstruction quality in terms of NRMSE and the difference between the original and reconstructed ECG signal versions. The algorithm has been applied to a set of ECG signal data exhibiting each a cardiac status: Normal ECG, abrupt transient, huge baseline wandering, APCs and PVCs. The obtained compression ratio values are around 11:1 while the reconstruction quality in terms of NRMSE and mean of the difference are, respectively, around 0.1% and 10^{-4}. These obtained results show the high performance of the proposed QRLE compression method. Moreover, a comparative study with respect to selected ECG compression algorithms show the higher performance of the developed new technique called 'Quantized run length encoding QRLE'.

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